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CLINICAL STUDY

Comparison of second-generation cryoballoon ablation and quantitative radiofrequency ablation guided by ablation index for atrial fibrillation

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ABSTRACT

BACKGROUND: Radiofrequency ablation and cryoballoon ablation are the main methods of catheter ablation for patients with atrial fibrillation (AF). However, different ablation catheters have different efficacy and complication rates. This study aimed to compare the efficacy and complication rates of quantitative radiofrequency ablation guided by ablation index (RFCA-AI) with those of second-generation cryoballoon ablation (CBA-2).

METHODS: A total of 230 consecutive patients with symptomatic AF undergoing a first ablation procedure of CBA-2 (92 patients) or RFCA-AI (138 patients) were enrolled in this study.

RESULTS: The late recurrence rate in the CBA-2 group was higher than that in the RFCA-AI group (p=0.012). Subgroup analysis showed the same result in patients with paroxysmal AF (PAF) (p=0.039), but no difference was found in patients with persistent AF (p=0.21). The average operation duration in the CBA-2 group (85 (75–99.5) min) was shorter than that in the RFCA-AI group (100 (84.5–120) min), but the average exposure time in the CBA-2 group (17.36 (13.87–22.49) min vs 5.49 (4.00–8.24) min; $p < 0.0001$) and X-ray dose (223.25 (149.15–336.95) min vs 109.15 (80.75–168.7) min; $p < 0.0001$) were significantly longer than those in RFCA-AI group. The patients were then divided into a late recurrent group and a late recurrence-free group. Multivariate logistic regression analysis showed that left atrial diameter (LAD), early recurrence, and methods of ablation (cryoballoon ablation) were independent risk factors for late recurrence after AF ablation.

CONCLUSION: For patients with PAF, CBA-2 was inferior to RFCA-AI. Furthermore, although RFCA-AI had an equivalent complication rate and longer operation time than CBA-2, it also had a shorter exposure time and required a lower radiation dose. The early recurrence of AF and LAD were independent risk factors for predicting late recurrence after AF ablation *(Tab. 5, Fig. 3, Ref. 29)*. Text in PDF *www.elis.sk*

KEY WORDS: atrial fibrillation; cryoablation; radiofrequency ablation; second-generation cryoballoon; ablation index.

Introduction

Pulmonary vein isolation (PVI) is the cornerstone of catheter ablation for atrial fibrillation (AF), and it is one of the most widely understood and commonly used methods of catheter ablation for the treatment of paroxysmal AF (PAF). Currently, PVI with catheter ablation is the main operative mode for PAF and plays an important role in the treatment of persistent AF (PeAF) (1–4).

At present, the main ablation methods are cryoballoon ablation and radiofrequency ablation. Relevant studies have shown that there is no difference in the efficacy of contact force catheter-guided radiofrequency ablation and second-generation cryoballoon ablation (CBA-2) in the treatment of AF (5). In addition, compared with contact force catheter-guided radiofrequency ablation, quantitative radiofrequency ablation guided by ablation index (RFCA-AI) further reduces the long-term recurrence rate after radiofrequency ablation of AF (6–10).

Gupta. et al. indirectly compared RFCA-AI with other catheter ablations, including CBA-2, and found that 12-month freedom from atrial arrhythmia relapse was significantly higher in patients treated with RFCA-AI than in those treated with CBA-2 (11). However, the relevant literature includes no direct comparison of RFCA-AI and CBA-2 in a real-world clinical setting. Therefore, the present study proposed the following hypothesis: RFCA-AI has better efficacy and a lower complication rate than CBA-2. The study analyzed the clinical data and postoperative follow-up results of patients with symptomatic AF who underwent CBA-2 or

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RFCA-AI, compared the efficacy and safety of these two types of ablation catheter, and explored the risk factors of late recurrence after AF ablation.

Materials and methods

Study population

A total of 230 consecutive patients with symptomatic AF undergoing a first ablation procedure of CBA-2 (92 patients) or RFCA-AI (138 patients) were enrolled in this study. All patients signed an informed consent form before undergoing the treatment, and the local ethics committee approved the study.

PAF and PeAF were defined according to the European Society of Cardiology, European Heart Rhythm Association, and the European Stroke Organization 2020 Guidelines for the management of AF. All patients underwent esophageal ultrasound or left atrial computed tomography angiography (CTA) examination before the arranged catheter ablation procedure to rule out thrombosis in the left atrium and/or left atrial appendage. At the same time, pulmonary vein CTA was performed to understand the anatomy of the patient's pulmonary vein. All antiarrhythmic drugs were discontinued for at least five half-lives before the procedure.

Patients were excluded from this study based on the following criteria: (1) age < 18 years or > 80 years; (2) patients with valvular AF; (3) patients with hyperthyroidism; (4) patients with a history of surgery or who were complicated with cerebrovascular accidents and other neurological diseases in the last three months; (5) patients with other systemic diseases or tumors; (6) patients with left atrium and/or left atrial appendage with thrombus; (7) preoperative pulmonary vein CTA suggested pulmonary vein anatomy co-intervention; (8) patients with non-pulmonary venous origins of AF; (9) patients who had undergone previous cardiac surgery or were combined with cardiac disease requiring surgery; (10) patients with incomplete clinical data or who failed to attend the follow-ups.

The procedure for RFCA-AI

The patient was placed in a supine position, and local anesthesia was induced with 1% lidocaine after routine disinfection. Mapping electrodes were positioned in the coronary sinus after puncturing the left femoral vein and inserting the sheath. Next, two Swartz sheaths were introduced into the left atrium using a dual transseptal puncture technique via the right femoral vein, and 100 units/kg of heparin sodium was given immediately after the first transseptal puncture. A pulmonary vein annular mapping catheter (Lasso", Biosense-Webster, Johnson & Johnson) and the CARTO-specific cold brine perfusion catheter (Navi-Star Thermo-Cool, Medtronic Inc) were then delivered to the pulmonary vein. A SMARTTOUCH SF catheter was used for point-by-point ablation in a power rate control mode of 50W, with an injected saline flow rate of 18 mL/min.

The parameters of the automatic point-taking system of the Visitag module were set as follows: catheter stable movement range 2.5 mm, pressure > 5 g, duration of stability > 3 s, distance between adjacent points 6 mm, and diameter of points 4 mm. The ablation index (AI) was set as 450 in the left atrial ridge, 360 in the left posterior wall, and 400 in the bottom of the left atrium. Under the guidance of AI, pulmonary vein vestibular linear ablation was performed to electrical isolation of the pulmonary vein. For patients with PeAF, other ablation lines (the left tricuspid isthmus, left roof, left atrial bottom, left anterior atrial wall, left posterior atrial wall, coronary sinus, etc.) were performed depending on the intraoperative situation.

Postoperative observation lasted for 20 minutes to confirm that electrical conduction between the bilateral pulmonary veins and left atrium was not recovered and atrial tachycardia could not be induced after 300–160 ms of stimulation. If sinus rhythm

Tab. 1. Patient characteristics.

Clinical characteristics	RFCA-AI group (n=138)	CBA-2 group (n=92)	p
Male (%)	79 (57.25%)	48 (52.17%)	0.449
Age (years)	61 (52, 67)	60.5 (53.25, 66)	0.973
Course of AF (months)	24 (7.75,60)	24 (3.25, 48)	0.338
BMI (kg/m2)	24.45±3.54	24.54±3.01	0.83
Smoke (%)	33 (23.91%)	18 (19.57%)	0.437
Alcohol (%)	14 (10.14%)	10 (10.87%)	0.86
CHA2DS2-VASc score	2 (1.3)	2 (1.3)	0.883
HASBLED score	1 (0.1)	1 (0.1)	0.683
PeAF (%)	29 (21.01%)	27 (29.35%)	0.149
Echocardiographic parameters			
LVEDD (mm)	47.39±3.70	47.47±4.50	0.894
LVESD (mm)	29.60 (27.48, 31.75)	28.70 (26.53, 32.08)	0.268
LAD (mm)	36.30 (32.28, 40.90)	35.70 (33.15, 39.43)	0.518
LVEF (%)	66.50 (62.18, 71.80)	68.60 (63.70, 72.00)	0.227
E/E'	11.45 (8.7, 14.02)	10.25 (8.33, 13.48)	0.852
Biochemical indexes			
NT-proBNP (pg/ml)	126.5 (43,3 99.75)	141.5 (61.25, 360.75)	0.182
Scr (umol)	74.87±15.46	73.59±18.34	0.581
Accompanying disease			
Hypertension	59 (42.75%)	33 (35.87%)	0.296
Diabetes	21 (15.22%)	7 (7.61%)	0.094
CAD	9 (6.52%)	7 (7.61%)	0.717
HLP	41 (29.71%)	31 (33.70%)	0.523
HCM	4 (2.90%)	4 (4.38%)	0.717
Postoperative AF			
Amiodarone therapy	35 (25.36%)	30 (32.61%)	0.232
Propafenone therapy	27 (19.57%)	24 (26.09%)	0.243
b-blocker therapy	26 (18.84%)	12 (13.04%)	0.246

BMI – Body Mass Index; LVEDD – Left Ventricular End-diastolic Diameter; LVESD – Left Ventricular End-systolic Diameter; LAD – Left Atrial Diameter; LVEF – Left Ventricular Ejection Fraction; NT-proBNP – N-terminal pro-B-type Natriuretic Peptide; Scr – Serum Creatinine; E – Early Diastolic Transmitral Velocity; E' – Early Diastolic Mitral Annular Velocity

Tab. 2. Procedural data and complications.

	RFCA-AI group (n=138)	CBA-2 group (n=92)	p
Procedure duration (min)	100 (84.5,120)	85 (75, 99.5)	<0.0001
Fluoroscopy duration (min)	5.49 (4.00, 8.24)	17.36 (13.87, 22.49)	<0.0001
X-ray exposure (mGym)	109.15 (80.75, 168.7)	223.25 (149.15, 336.95)	<0.0001
Electrical cardioversion	29 (21.01%)	25 (27.17%)	0.28
Severe complications			
Phrenic nerve palsy	1	3	0.305
Cardiac tamponade	2	0	0.518
Hydropericardium	1	0	1
Postoperative pneumonia	1	0	0.565
Total complications	5	5	0.526

was not restored after ablation, 100–150-J synchronous electrocardiography was performed. The catheter and sheaths were then withdrawn, wound pressure was applied to stop the bleeding, and sterile gauze was used for pressure bandaging.

The procedure for CBA-2

The patient was placed in a supine position, and local anesthesia was induced with 1 % lidocaine after routine disinfection. Two mapping electrodes were positioned in the coronary sinus and superior vena cava after puncturing the left femoral vein and inserting the sheath. After local infiltration of 1% lidocaine, the right femoral vein was punctured to deliver the long sheath, and the atrial septum was punctured to deliver a J-shaped guide wire to the left upper pulmonary vein and lead the sheath tube to the left atrium. An intravenous injection of 100 units/kg heparin sodium was then given, and bilateral pulmonary venography was performed.

The J-shaped guide wire was used to exchange the cryoballoon delivery sheath and deliver the 28 mm-long second-generation cryoballoon with an Achieve catheter. The cryoballoon was placed successively in the upper left, lower left, upper right, and lower right of the pulmonary vein antrum. After good sealing, cryoablation was performed to electrical isolation of the pulmonary vein. When isolating the right pulmonary vein, the diaphragmatic nerve was stimulated. Once the diaphragmatic movement was weakened or had disappeared, the cryoablation was stopped immediately until diaphragmatic movement returned to normal. For patients with PeAF, if sinus rhythm was not restored after ablation, 100–150-J synchronous electrical cardioversion was performed. The catheter and sheaths were withdrawn, wound pressure was applied to stop the bleeding, and sterile gauze was used for pressure bandaging.

Follow-up

No antiarrhythmic medication was prescribed after catheter ablation. If there was documented recurrence of symptomatic AF during this time, these patients will require antiarrhythmic drug therapy. Warfarin or novel oral anticoagulant therapy after the first three months was based on the patient's wishes, and an anticoagulant strategy was continued according to the patient's CHA2DS2-VASC score. All patients were off antiarrhythmic therapy at three months post-ablation.

After discharge, follow-up systematic outpatient visits were conducted at 3, 6, 9, 12, and 15 months or whenever symptoms occurred after catheter ablation. The follow-up examinations included a 12-lead electrocardiogram and 24-h Holter monitoring. Patients were also given general follow-ups once a month and asked about the recurrence of AF after surgery, including symptoms like palpitations, chest tightness, shortness of breath, fatigue, and other clinical indications. Patients were informed to do a 12-lead electrocardiogram nearby when these symptoms occurred.

Study endpoints

The study endpoint was defined by the late recurrence of AF, defined as any atrial arrhythmia lasting ≥ 30 s after the blanking period for three months after catheter ablation.

Statistical analysis

Nominal values were expressed as n (%) and compared using a χ^2 test. The Kolmogorov–Smirnov test was used to assess the normality of distribution in comparison with baseline characteristics. Comparisons between two groups were made using Student's t-test and summarized as mean ± standard deviation for independent samples if normally distributed or, if not normally distributed, evaluated using the Mann–Whitney U-test and expressed as medians and quartiles. The rate of late recurrence was assessed by Kaplan–Meier analysis using a log-rank test. Logistic regression analysis was used to analyze the correlation between variables. $p < 0.05$ was considered statistically significant. SPSS version 25.0 (SPSS Inc, Chicago, IL, USA) was used for descriptive and inferential statistical analysis.

Results

Baseline population characteristics

Of the 230 patients, 92 underwent CBA-2 and 138 underwent RFCA-AI. There was no significant difference between the two groups in terms of patient characteristics (Tab. 1).

Procedural results

The mean procedure duration was significantly longer in the RFCA-AI group than in the CBA-2 group (85 (75–99.5) vs 100 (84.5–120) min; $p < 0.0001$). Mean fluoroscopy time and X-ray dose were significantly longer in the CBA-2 group than in the RFCA-AI group (17.36 (13.87–22.49) vs 5.49 (4.00–8.24) min and 223.25 (149.15–336.95) vs 109.15 (80.75–168.7) min; $p < 0.0001$). No significant difference was found between the CBA-2 group and the RFCA-AI group in external direct current cardioversion (25 (27.17 %) vs 29 (21.01 %); $p = 0.280$). The procedural results are shown in Table 2.

Long-term efficacy

Patients were followed up for up to 15 months after the procedure. The median follow-up duration was 9 months (interquartile

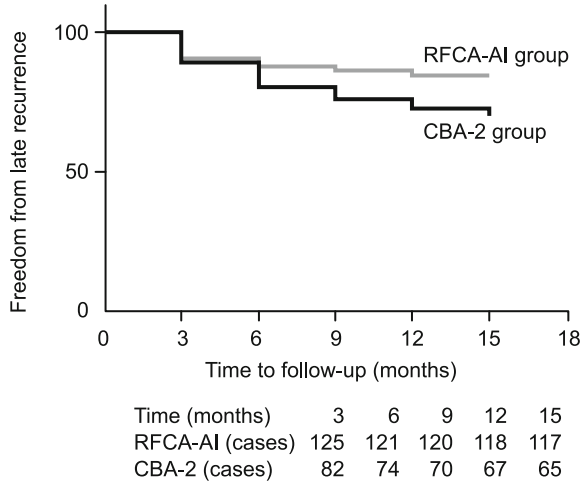

Fig. 1. The Late Relapsed-Free Survival Curves Of Paf Group Cba -2 And Rfca-Ai.

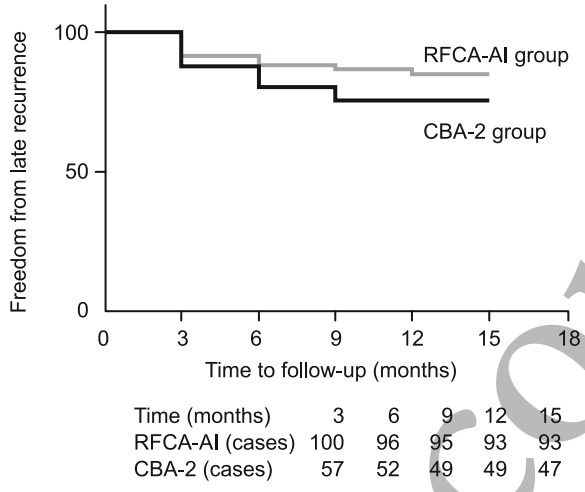

Fig. 2. The Late Relapsed-Free Survival Curves Of Paf Group Cba -2 And Rfca-Ai.

range: 6–13 months) for the CBA-2 group and 8 months (interquartile range: 5–12 months) for the RFCA-AI group. In the CBA-2 group, 27 (29.35 %) patients suffered from late recurrence vs 21 (15.22 %) patients in the RFCA-AI group.

Kaplan–Meier survival analysis with a log-rank test showed that patients in the CBA-2 group had a significantly higher late recurrence rate than those in the RFCA-AI group (p = 0.012) (Fig. 1). It also showed that the late recurrence rate for patients with PAF in the CBA-2 group was higher than that for the same patients in the RFCA-AI group (p = 0.039) (Fig. 2). No significant difference was found between the two groups in the late recurrence rate for patients with PeAF (p = 0.21 (Fig. 3). The late recurrence rates are shown in Table 3.

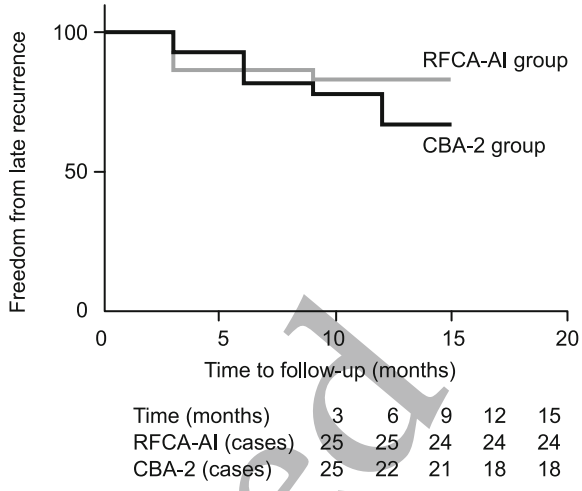

Fig. 3. The Late Relapsed-Free Survival Curves Of Peaf Group Cba -2 And Rfca-Ai.

Complications

In the CBA-2 group, transient phrenic nerve palsy occurred in three patients and postoperative pneumonia in two patients. In the RFCA-AI group, cardiac tamponade occurred in two patients, phrenic nerve palsy in one patient, pericardial effusion in one patient, and postoperative pneumonia in one patient. There was no significant difference between the two groups in terms of the incidence of complications (p > 0.05). All patients with complications were improved before discharge, and those with phrenic nerve palsy recovered. The complications experienced by the patients are detailed in Table 2.

Analysis of risk factors for postoperative recurrence

All patients were divided into two groups according to the late recurrence of AF. The results of the univariate analysis are listed in Table 4. The univariate analysis revealed that the early recurrence of atrial arrhythmia (p = 0.010), left atrial diameter (LAD) (p = 0.029), and CBA-2 (p = 0.010) were risk factors that affected the late recurrence of AF (p < 0.05). No statistical differences were

Tab. 3. Late recurrence.

Methods of ablation	AF type	Recurrence				No recurrence
		Total	Atrial flutter	Atrial fibrillation	Atrial tachycardia	
CBA-2 (n=92)	PAF (n=65)	18 (27.7%)	3 (4.6%)	13 (20%)	2 (3.1%)	47 (72.3%)
	PeAF (n=27)	9 (33.3%)	2 (7.4%)	7 (25.9%)	0 (0.0%)	18 (66.7%)
RFCA-AI (n=138)	PAF (n=109)	16 (14.7%)	2 (1.8%)	13 (11.9%)	1 (0.9%)	93 (85.3%)
	PeAF (n=29)	5 (17.2%)	1 (3.4%)	4 (13.8%)	0 (0.0%)	24 (82.8%)

Tab. 4. Patient characteristics.

Clinical characteristics	Recurrence (n=182)	No recurrence (n=48)	p value
Male (%)	104 (57.14%)	23 (47.92%)	0.253
Age (years)	60 (51,67)	62 (54.5,66)	0.363
Course of AF (months)	24 (5,48)	24 (12,60)	0.2
BMI/ (kg/m^2)	24.47±3.38	24.47±3.17	0.981
Smoke (%)	37 (20.33%)	14 (29.17%)	0.19
Alcohol (%)	17 (9.34%)	7 (14.58%)	0.281
CHA2DS2-VAS score	2 (1,3)	2 (1,3)	0.21
Hasbled score	1 (0,1)	1 (0,1)	0.542
PeAF (%)	42 (23.08%)	14 (29.17%)	0.382
Cryoablation (%)	65 (35.71%)	27 (56.25%)	0.01
Electrical Cardioversion (%)	41 (22.53%)	13 (27.08%)	0.508
Echocardiographic parameters			
LVEDD (mm)	47.35 (44.4,49.6)	47.40 (45.75,50.23)	0.542
LVESD (mm)	29.61±3.88	29.93±3.74	0.611
LAD (mm)	35.91±6.24	38.07±5.31	0.029
EF (%)	67.20 (62.38,72.00)	68.55 (63.25,71.10)	0.923
E/E‘	11.05 (8.80,13.73)	10.40 (8.00,13.95)	0.367
Biochemical indexes			
NT-proBNP (pg/ml)	108.5 (43.00,410.00)	177 (69.50,366.75)	0.21
HDL-C (mmol/L)	1.18 (0.97,1.39)	1.19 (0.94,1.33)	0.662
LDL-C (mmol/L)	2.94±0.94	3.07±1.13	0.411
TC (mmol/L)	4.3 (3.76,5.07)	4.68 (3.92,5.41)	0.163
TG (mmol/L)	1.27 (0.95,1.73)	1.46 (0.97,1.99)	0.22
Scr (umol)	74.57±16.32	73.56±17.96	0.711
Accompanying disease			
Hypertension	71 (39.01%)	21 (43.75%)	0.551
Diabetes	21 (11.54%)	7 (14.58%)	0.566
CAD	10 (5.49%)	6 (12.50%)	0.11
HLP	53 (29.12%)	19 (39.58%)	0.164
HCM	5 (2.75%)	3 (6.25%)	0.369
Postoperative AF			
Amiodarone therapy	56 (30.77%)	17 (35.42%)	0.538
Propafenone therapy	43 (23.63%)	8 (16.67%)	0.302
b-blocker therapy	32 (17.58%)	6 (12.50%)	0.399
Early recurrence	40 (21.98%)	20 (41.67%)	0.01

BMI – Body Mass Index; LVEDD – Left Ventricular End-diastolic Diameter; LVESD – Left Ventricular End-systolic Diameter; LAD – Left Atrial Diameter; LVEF – Left Ventricular Ejection Fraction; NT-proBNP – N-terminal pro-B-type Natriuretic Peptide; Scr – Serum Creatinine; E – Early Diastolic Transmitral Velocity; E‘– Early Diastolic Mitral Annular Velocity

found between the two groups in gender, age, AF duration, body mass index, smoking and alcohol history, echocardiography (left ventricular end-diastolic diameter, left ventricular end-systolic diameter, left atrial diameter, ejection fraction, early diastolic transmitral velocity/early diastolic mitral annular velocity), comorbidity, and postoperative medication.

The results of the univariate analysis are listed in Table 4. All variables ($p < 0.2$) mentioned in Table 4 were included in the multiple logistic analysis. The results of this analysis are summarized in Table 5. The multiple logistic regression analysis identified that the left atrial diameter (OR: 1.075, 95% CI: 1.004–1.152, $p = 0.038$), early recurrence (OR: 2.414, 95% CI: 1.151–5.063, $p = 0.020$), and CBA-2 (OR: 2.367, 95 % CI: 1.170–4.790, $p = 0.017$) were independent predictors for the late recurrence of AF.

Discussion

Main findings

The present study found that, for patients with PAF, the efficacy of RFCA-AI was better than that of CBA-2. For patients with PeAF, however, the efficacy of the two groups was found to be equivalent. Both RFCA-AI and CBA-2 were found to be safe, and the complication rates were equivalent between the two groups. However, although the RFCA-AI group had a shorter exposure time and lower radiation dose than the CBA-2 group, the operation time was longer. The LAD and early recurrence of AF were independent risk factors for predicting late recurrence after AF ablation.

The use of RFCA-AI vs CBA-2 for PVI in AF

Since the discovery that ectopic activity in the pulmonary veins is a major trigger for AF, PVI has become the cornerstone of AF ablation. Recent years have seen growing use of cryoballoon-based PVI, which has proven to be an interesting alternative to radiofrequency ablation (12, 13). Cryoballoon ablation has a shorter learning curve, shorter operative time, and less pain for patients – advantages being increasingly favored by physicians. Cryoballoon technology has evolved with the advent of the second-generation cryoballoon. Compared with the first-generation cryoballoon, the second-generation cryoballoon has twice as many injection ports, which are positioned more distally on the catheter’s shaft, resulting in a larger and more uniform zone of freezing on the cryoballoon’s surface. Previous studies have shown that the mean procedure and fluoroscopy times are shorter and the success rate higher when using the second-generation cryoballoon (14–16). However, there are some limitations in the application of this technique: its surgical indications are narrower than those of radiofrequency ablation, and it is difficult to complete linear ablations other than PVI. In addition, it has certain requirements for pulmonary vein anatomy, and its efficacy for the treatment of AF in patients with abnormal pulmonary vein anatomy is poor.

Point-to-point radiofrequency ablation has certain advantages for pulmonary veins with abnormal anatomy. However, a lack of previous experience in point-to-point radiofrequency ablation and inaccurate assessment of damage results in a certain percentage of pulmonary vein reconnection and complications, and its advantages are offset. The AI, a novel ablation quality marker, accurately represents the degree of ablation damage. Its use may be

Tab. 5. Analysis of risk factors for late recurrence.

Variables of multivariate regression analysis	OR	95% confidence interval		p
		Lower bound	Upper bound	
Smoke	1.721	0.785	3.770	0.175
LAD	1.075	1.004	1.152	0.038
Early recurrence	2.414	1.151	5.063	0.020
Ablation procedure (cryoballoon ablation)	2.367	1.170	4.790	0.017
TC	1.103	0.803	1.154	0.546
Hyperlipemia	1.542	0.733	3.244	0.254
Coronary heart disease	2.660	0.843	8.400	0.095
Type of atrial fibrillation (persistent atrial fibrillation)	0.785	0.331	1.860	0.583
Age	1.011	0.975	1.048	0.552
Course of disease	1.004	0.996	1.012	0.355

LAD – Left Atrial Diameter; TC – Total Cholesterol

the reason why RFCA-AI has been found to be better than point-to-point radiofrequency ablation, contact force catheter-guided radiofrequency ablation, and automatic point extraction ablation. Recently, a single-center retrospective study reported that the need for repeat PVI in AF and the occurrence of PV reconnection at second PVI significantly decreased (17).

A recent study by Das. et al. found that an AI value of 480 for anterior/roof segments and an AI value of 370 for posterior/inferior segments was required to avoid reconnection (18). Based on these results, a multicenter prospective study suggested that the minimal lesion depth defined by the AI should reach the value of at least 400 at the posterior/inferior wall and at least 550 at the anterior/roof wall, with a maximum interlesion distance not exceeding 6 mm. Taghi et al (19) targeted AI ≥ 400 at the posterior/inferior wall and AI ≥ 550 at the anterior/roof wall and observed that freedom from late recurrence of atrial fibrillation was 91.3 % in 104 patients who stopped taking antiarrhythic drugs.

Different doctors perform PVI procedures very differently, and anatomical studies indicate that tissue thickness varies considerably between different left atrial regions. Currently, there is a lack of individualized AI values to guide clinical ablation. Lower AI values are associated with reconnection, and high AI values may lead to excessive ablation and increased complications, such as tamponade and adjacent tissue damage. Therefore, AI values need to be evaluated and validated before clinical application. This may also be a direction for future research.

Efficacy

The results of the present study are in line with the results of other previous studies, suggesting that RFCA-AI is better than CBA-2 for patients with PAF. However, the present study also found that RFCA-AI and CBA-2 had similar efficacy for patients with PeAF. There are two possible reasons for this. First, the mechanism of triggering and maintaining PeAF is complex, and recent studies have shown that patients with PeAF have a maintenance mechanism in addition to a trigger mechanism, but the exact mechanism remains unclear. Moreover, many studies have confirmed that the efficacy of additional ablation lines is not exact, so there is no optimal ablation strategy. Second, the number of patients with PeAF in the present study was small, and the follow-up time was short, which may not be enough to reflect the actual situation.

Procedure and fluoroscopy times

In the present study, there were significant differences between the two groups in procedure time, fluoroscopy time, and exposure time. Similar to previously described experience (20, 21), the CBA-2 group had shorter procedure times than the RFCA-AI group. However, mean fluoroscopy times and exposure times were shorter in the RFCA-AI group than in the CBA-2 group. Point-to-point radiofrequency ablation and additional ablation lines were added in some patients of RFCA-AI group, thereby increasing the total procedure time. In addition, CBA-2 requires longer fluoroscopy times and exposure times to justify balloon placement and ensure PVI.

Complications

There were very few severe complications in the present study, demonstrating the safety of both techniques when used in an experienced center. No significant difference was found between the RFCA-AI group (3.62 %) and CBA-2 group (5.43 %) in terms of complications.

Phrenic nerve palsy is the most common complication of cryoballoon ablation (22). Twenty-three studies were included in a meta-analysis that identified the incidence of phrenic nerve palsy as 6.38 % of 1,349 cases (23). Armin et al and Aryana et al (24, 25) compared CBA-2 and Open-Irrigated radiofrequency and found that the rate of phrenic nerve palsy in the CBA-2 group was higher than that in the Open-Irrigated radiofrequency group. However, the present study found that the incidence of phrenic nerve palsy in the CBA-2 group was not high. There may be two reasons for this. First, the operation as performed in the center in which the present study was conducted is mature, and the surgeons have a wealth of experience of ablation. Second, during the pacing of the phrenic nerve while isolating the right pulmonary vein, cryoablation was immediately stopped when diaphragmatic movement had weakened or disappeared, which greatly reduces the risk of phrenic nerve palsy.

Analysis of risk factors for postoperative recurrence

The triggering and maintenance mechanisms that lead to the onset and persistence of AF have not yet been completely elucidated. Many factors have been considered to predict late recurrence of AF, including LAD, early recurrence, AF type, patient age, and duration of AF (26–28). In the present study, the patients were divided into recurrence and non-recurrence groups. A statistical difference was found between the two groups in terms of LAD, early recurrence, and method of ablation (CBA-2), and multivariate logistic regression analysis showed that these three

factors were independent risk factors for late recurrence after AF ablation. This indicates that the efficacy of RFCA-AI is better than that of CBA-2.

Left atrial dilation can induce myocardial structural and electrophysiological changes and cause dysfunction and AF (29), and it is a relatively certain predictive factor for the late recurrence of AF. The late recurrence of AF may also be caused by inflammation and edema caused by surgery, as well as by pulmonary vein reconnection and inadequate pulmonary vein antrum isolation, in addition to the early recurrence of AF. Therefore, it is suggested that early recurrence is very valuable in predicting the late recurrence of AF.

Limitations

The present study had some limitations. First, it was a single-center, non-randomized, observational study that conducted retrospective analysis on a limited number of patients. Future larger randomized studies with longer follow-up periods are therefore needed to observe the long-term efficacy and safety of the studied techniques. Second, the choice of catheter ablation was not random but based on each patient's wishes. Last, no long-term monitoring was performed, so the arrhythmia recurrence rate and asymptomatic episodes may have been underestimated.

Conclusion

The present study found that, for patients with PAF, RFCA-AI had better efficacy than CBA-2, but for patients with PeAF, the efficacy of the two techniques was equivalent. The RFCA-AI group had a shorter exposure time and lower radiation dose than the CBA-2 group, but the operation time was longer. The study also found that RFCA-AI and CBA-2 are both safe, with the complication rates being equivalent between the two groups. Finally, LAD and early recurrence of AF were found to be independent risk factors for predicting late recurrence after AF ablation.

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